EVALUATION OF THE HEALTH RISK TO THE PUBLIC AND WORKERS ASSOCIATED WITH THE SHIPMENT OF DEFUELED REACTOR COMPARTMENTS FROM CRUISERS AND LOS ANGELES CLASS AND OHIO CLASS SUBMARINES

Appendix E

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1. INTRODUCTION

This appendix presents an evaluation of the health risks to the public and occupational workers associated with the transportation of defueled reactor compartments fro decommissioned U.S. Navy nuclear-powered cruisers and submarines. It is applicable to the cruisers USS LONG BEACH (CGN 9), USS BAINBRIDGE (CGN 25), USS TRUXTUN (CGN 35), the two cruisers of the USS CALIFORNIA Class (CGN 36 and CGN 37), the four cruisers of the USS VIRGINIA Class (CGN 38, CGN 39, CGN 40, CGN 41), USS LOS ANGELES Class submarines, and USS OHIO Class submarines. BAINBRIDGE, TRUXTUN, and CALIFORNIA Class cruisers were not analyzed individually and are considered to be equivalent to VIRGINIA class cruisers for purposes of this evaluation due to similarity of reactor plant design. Shipments from either Puget Sound Naval Shipyard (PSNS) or Norfolk Naval Shipyard (NNSY) to either the Hanford disposal site or Savannah River disposal site are covered. For the shipment of reactor compartments from PSNS to Hanford, the reactor compartments are assumed to be shipped whole or subdivided into smaller packages. For all other cases, the reactor compartments are assumed to be subdivided into smaller packages. Whole reactor compartment shipments from NNS or to the Savannah River disposal site are not possible due to physical limitations such as the depth of the river and overhead obstructions due to bridges.

2. SHIPMENTS EVALUATED

The package origin/destination options and the modes of transportation considered for various package types are summarized in Table E-1.

3. TECHNICAL APPROACH - GENERAL

The general approach taken to evaluate the radiological health risks (i.e., increase in potential of cancer fatalities) associated with the transport of the subject reactor compartment packages is described as follows. First, the radiological risks to the general population, to the transport crew, and to hypothetical maximum exposed individuals are evaluated for gamma radiation emanating directly from the package for normal transport (i.e., incident-free) conditions. Next, the radiological risks to the general population for accident scenarios resulting in corrosion product release to the atmosphere are evaluated based on a conditional probability for occurrence of accidents with various severity. To upper bound the significance of an accident, the radiological consequences assuming a severe accident has occurred are also evaluated for hypothetical maximum exposed individuals and the general population. In conjunction with these incident-free and accident radiological evaluations, non-radiological risks to the population are presented from causes associated with vehicular exhaust emissions and transportation accidents.

3.1 Computer Codes

Several computer codes were used in the analyses. Specifically, the RADTRAN 4 computer code, developed by Sandia National Laboratories, was used to calculate the radiological risk for both the incident-free and accident risk scenarios (SNL, 1992 and SNL, 1993). For this evaluation, RADTRAN was determined not to be appropriate for the consequence analyses or assessment of maximum exposed individuals (MEI).

The RISKIND computer code, developed by Argonne National Laboratory, was used to calculate the maximum radiological consequences to the general population and to individuals for postulated accident condition (ANL, 1993). For this evaluation, RISKIND was determined not to be appropriate for the risk analyses aspect or incident-free evaluation.

Table E-1 Package Origin/Destination and Transport Mode

ITEM		MODE			ORIGIN		DESTINATION	
	Package Type	Truck	Rail	Barge/ Transporter	PSNS	NNS	Hanford	Savannah River
A	Whole Reactor Compartment			•	•		•	
B	Miscellaneous Components	•			•	•	•	•
C	Reactor Pressure Vessel			•	•	•	•	•
D	Steam Generator	(a)	(b)		•	•	•	•
E	Pressurizer		•		•	•	•	•

(a)   Steam generators from cruisers assumed to be shipped by truck.
(b)   Steam generators from submarines assumed to be shipped by rail.

Several other codes were used to provide input for the RADTRAN 4 and RISKIND computer codes. These codes include INTERLINE, HIGHWAY, and SPAN 4.

The INTERLINE computer code, developed by Oak Ridge National (ORNL) Laboratory, was used to evaluate rail routes for particular shipments and provides mileage and population densities in the rural, suburban and urban segments of the route (ORNL, 1993a). INTERLINE is an interactive computer program designed to simulate routing using the U.S. rail system. The INTERLINE code used is the latest available from ORNL and contains the 1990 census data.

The INTERLINE database consists of networks representing various competing rail companies in the U.S. The routes used in this evaluation use the standard assumptions in the INTERLINE model which simulates the selection process that railroads would use to direct shipments of the items under consideration. The code is updated periodically to reflect current track conditions and has been benchmarked against reported mileage and observations. INTERLINE also provides the weighted population densities for rural, suburban, and urban populations averaged over all states along the shipment route and the percentage of mileage traveled in each population density. The distance traveled, weighted population density, and percentage of distance in each population density are input variables in the RADTRAN 4 code.

The HIGHWAY computer code also developed by ORNL, was use to evaluate the truck routes excluding the partial routes by truck (transporter) for the whole reactor compartment and reactor pressure vessel (ORNL, 1993b). HIGHWAY is an interactive computer code designed to simulate routing using the U.S. highway system.

The HIGHWAY code used in this evaluation is the latest available from ORNL. The code is updated periodically as new roads are added. The routes used for this study use the standard assumptions in the highway model. HIGHWAY provides the distance between the origin and destination, the weighted population densities along the routes and the percentage of distance traveled in each population density, which are all input variables for the RADTRAN 4 computer code.

The SPAN 4 computer code (Bettis, 1972) was used to perform gamma exposure rate calculations for the various shipping containers to assess the effect of increased distance from the source on exposure. SPAN 4 is a point kernel code where appropriate exponential kernels are integrated over a source distribution. SPAN 4 was developed by the Bettis Atomic Power Laboratory specifically for naval spent nuclear fuel and associated reactor components.

3.2 Conversion to Fatality Rates

The radiological impacts are first expressed as the calculated total effective exposure (person-rem) for the exposed population, transportation crew, and the maximum exposed individuals. The calculated total exposures are then used to estimate the hypothetical health effects, expressed in terms of estimated cancer fatalities. The health risk conversion factors used in this evaluation are taken from the International Commission on Radiological Protection (ICRP, 1991) which specifies 0.0005 latent cancer fatalities per rem for members of the public and 0.0004 latent cancer fatalities per rem for workers. These conversion factors assume no radiological threshold occurs. Therefore, upon interpreting the results, the risks associated with population exposure (person-rem) and maximum exposed individual (rem) are equivalent for equal exposure levels. For example, the risk associated with 0.1 rem exposure to a population of 10 persons (1.0 person-rem) is equivalent to the risk from exposure of 1 rem to 1 individual (1 person-rem).

Non-radiological risks related to the transportation of naval reactor compartments are also estimated. The non-radiological risks are those resulting from vehicle exhaust emission for incident-free transportation and fatalities resulting from transportation accidents for accident risk assessment. The non-radiological risks associated with shipments required to return empty containers to the origin are also included. Risk factors for exhaust emissions and state level fatality rates (Saricks, 1994, SNL, 1982 and SNL, 1986) are summarized in Table E-2.

Table E-2   Fatality Rates for Non-Radiological Risks

	RAIL	TRUCK	WATERWAY
Fatalities/km due to Pollutants	1.3×10^{-7}	1.0×10^{-7}	0.0
Fatalities/km due to Accidents in Washington State	$*2.82 \times 10^{-8}$	1.47×10^{-8}	NA
Fatalities/km due to Accidents as a National Average	2.82×10^{-8}	5.82×10^{-8}	NA
Fatalities/km due to Accidents for the Pacific Coast	NA	NA	3.2×10^{-9}
Fatalities/km due to Accidents for the Atlantic Coast	NA	NA	3.2×10^{-9}
Fatalities/km due to Accidents for the Inland Waterways	NA	NA	7.3×10^{-9}

* Not readily available so national average was used.

4. TECHNICAL APPROACH FOR THE ASSESSMENT OF INCIDENT-FREE TRANSPORTATION

4.1 General Population Exposure and Transportation Crew Exposure

To assess the health risk associated with incident-free transportation of naval reactor compartments, the RADTRAN 4 computer code was used to calculate the external radiological exposure to the general population and the transportation crew. Exposures received during incident-free transport are attributed to gamma radiation emanating mainly from activated structures (Cobalt-60) within the reactor compartment package.

Included in the RADTRAN 4 computer code incident-free risk calculations for transport are models predicting:

(1) Exposure to persons within about one-half mile of each side of the transport route (off-link exposures).

(2) Exposures to persons (e.g., passengers on passing trains or vehicles) sharing the transport route (on-link exposures).

(3) Exposures to persons at stops (e.g., residents or rail and truck crew not directly involved with the shipment).

(4) Exposures to transportation crew members.

The exposures calculated for the three groups, (off-link, on-link and crew) were added together to obtain the general population exposure estimates. On-link was not included in the transporter shipment of whole reactor compartments and pressure vessels because it is assumed that access controls to the highway would be imposed.

The exposure calculated for the crew was assigned to occupational exposure.

The transportation crew exposure is associated with exposure directly from the package during transit and/or inspection periods. For truck/transporter shipments, RADTRAN assumes crew exposure is entirely from exposure during the transit period and no inspections occur. For both waterway and rail shipments, RADTRAN assumes crew exposure is from exposure during periods of package inspections and negligible during the transit time due to relatively long separation distances and massive shielding of intervening structures. This RADTRAN model was concluded to be reasonable for both truck and rail shipments but not for the treatment of the waterway shipments of interest.

For reactor compartment waterway shipment RADTRAN crew exposure predictions were concluded not to be applicable since no package inspections are performed (the package is welded to the barge) and intervening distances during transit is not always sufficient to entirely preclude crew exposure. Therefore, reasonable conservative hand calculations were performed to account for waterway crew exposures during transit using equivalent point source formulas (similar to the first formula presented in Section 5.2.) together with the data presented in Table E-7.

4.2 Maximum Exposed Individuals

To estimate the maximum radiological exposure to occupational and non-occupational individuals during routine transport of reactor compartments, various scenarios were hypothesized.

For exposure to the general population during rail shipments, three scenarios were assumed:

(1) A rail yard worker who was assumed to be working at a distance of ten meters from the package for two hours.

(2) A resident who was assumed to live 30 meters from the rail line while the package was being transported.

(3) A resident who was assumed to be living 200 meters from a rail stop where the reactor compartment package was sitting for 20 hours.

The maximum occupational exposure during rail shipments was assumed to be that occurring from inspections of the package as calculated by RADTRAN.

For truck shipments, the maximum exposed individual (general population) was hypothesized to be:

(1) A person who is caught in traffic and located 1.0 meters away from the reactor compartment package for one half hour.

(2) A resident assumed to be living 30 meters from the highway while the package was being transported.

(3) A service station worker who was assumed to be working at a distance of 20 meters from the package for 2 hours.

The maximum exposed occupational worker was assumed to be the driver of the truck as calculated in RADTRAN.

For the waterway shipments, the scenarios for the maximum exposed individual were:

(1) A bridge workman located 10 meters above the centerline of the package for 2 hours while stopped, and

(2) a motorist is disabled on a bridge above the water route during the total time the package is being transported and is positioned a distance above the water route equivalent to the package radius plus 10 meters.

The maximum exposed occupational worker was assumed to be a ship crew member during transit.

For predicting radiological exposure to persons at a fixed distance (the maximum exposed individual) from the package during a stop, the following formula was used.

Exposures to a person at a fixed distance from the container:

$$E = T \times K \times TI/D^2 \qquad \text{Formula (1)}.$$

where:

E	=	exposure
T	=	total exposure time
K	=	shipment external dose rate to exposure conversion factor based on package size
TI	=	shipment external dose rate at one meter from the package surface
D	=	average distance from centerline of container to exposed person

The maximum exposed individual is assumed to be the same individual for all shipments of the same type.

Exposure to individuals at a fixed distance from the transport route was calculated using the following formula for a moving radiation source traveling with a fixed velocity, V. All other terms are the same as described for Formula (1).

$$E = (\pi \times K \times TI)/(V \times D) \qquad \text{Formula (2)}$$

5. TECHNICAL APPROACH FOR POSTULATED ACCIDENTS

5.1 General Population and Risk

The RADTRAN 4 computer code was used to calculate the radiological risk to the general population under accident conditions. The RADTRAN 4 computer code evaluates six pathways for radiation exposures resulting from an accident. The six evaluated pathways are:

(1) Direct radiation exposure from the damaged package.

(2) Inhalation exposure from the plume of radioactive material released from the damaged package.

(3) Direct radiation exposure from immersion (cloudshine) in the plume of radioactive material released from the damaged package.

(4) Direct radiation exposure from ground deposition of the radioactive material released from the damaged package.

(5) Inhalation exposure from resuspension of the radioactive material deposited on the ground.

(6) Ingestion exposure from food products grown on the soil contaminated by ground deposition of radioactive material released from the damaged package.

For each pathway, a specific formula is used to determine an estimate of the radiological exposure from that particular pathway with the total radiation exposure equal to the sum of the exposure for each pathway. The internal pathways (inhalation and ingestion) exposures are based on a committed effective dose to the body over a 50-year period. The total accident radiation exposure accounts for the probability f an accident occurring and the probability of a accident of a particular severity. The general equation for the population risk from all pathways is:

$$DR = \Sigma_{c,r} L_c P_r \times \Sigma_{i,j,k} (P_j \times RF_j \times D_{i,j,k})$$

where:

DR	=	population exposure risk from the accident
L_c	=	shipment distance (Table E-3)
P_t	=	probability of traffic accidents per unit distance (Accident Probabilities, Table E-8)
P_r	=	probability of accident severity category (Severity Fractions, Table E-9)
RF_j	=	fraction of curies released from shipping container by severity category j (Corrosion Product Release Fractions, Table E-10)
$D_{i,j,k}$	=	radiation exposure commitment resulting from accident severity category j through pathway i in population density zone k.

Because it is impossible to predict the specific location of a transportation accident, neutral weather conditions (Pasquill Stability Class D) were assumed (Pasquill, 1974). Since neutral meteorological conditions are the most frequently occurring atmospheric conditions in the United States; these conditions are most likely to be present in the event of a transportation accident.

5.2 Maximum Consequence to Individual and Population

In addition to the estimation of the accident risk described above, the accident consequence was evaluated assuming an accident of the highest severity occurs. The consequence, expressed as radiological exposure, is calculated for the maximum exposed individual (MEI) and the general population. Exposures to the general population are calculated for each of the three population density regions (rural, suburban, and urban) over a 50-mile radius.

A fraction of the total corrosion product inventory in the package can be released to the atmosphere assuming a severe accident occurs. This release fraction was conservatively estimated to be 32% to 40% for whole reactor compartment shipments and varying amounts for subdivided shipments and was used in the consequence and risk analysis.

The RISKIND computer code, modified to accept the inventory associated with naval reactor compartment corrosion products was used to calculate the exposure. The pathways evaluated by RISKIND for the general population are identical to those used in the RADTRAN 4 computer code for the risk evaluation.

The MEI exposure includes the contributions from inhalation, groundshine and cloudshine. No food ingestion pathway to an individual is considered because it was assumed that radioactive contamination from plausible accidents would be cleaned up promptly and, therefore would not enter the food chain. Direct radiation exposure from the damaged package to the MEI and maximum exposed population would be less that 0.1% of the exposure from inhalation, groundshine, and cloudshine which would occur at 160m to 400m from the package. It was assumed that the MEI would be exposed unshielded during the passage of the plume of radioactive material released from the accident under worst (stable) atmosphere conditions.

Remedial actions following an accident would significantly reduce the consequences of an accident; however, no credit was taken in the risk or maximum consequence evaluations.

5.2.1 Probability Cutoff Criterion. Consistent with the U.S. Department of Energy's, Office of Environmental Management and Idaho National Engineering Laboratory, Environmental Waste Management Programs Environmental Impact Statement (DOE, 1995), a conservative severe accident probability cutoff criterion of one in ten-million (1×10^{-7}) was selected for excluding improbable accidents from the maximum consequence evaluation.

To determine the overall severe accident probability, the probability of an accident times the severity fraction times the fraction of travel in each population area times the probability of the meteorological conditions was calculated.

The probability of the accident per year was calculated by multiplying the accident probability rates times the distance traveled in each state times the maximum number of shipments per year. The number of shipments per year was conservatively assumed to be 8 complete reactor compartment shipments (except 2 for the LONG BEACH) for purposes of determining this cutoff probability. This was done for each combination of origin and destination and ship class.

To calculate the probability of the meteorological conditions, the established criteria for assigning atmospheric stability classes (Pasquill, 1974) was used. Pasquill Class D was considered to be equivalent to 50% meteorology; that is 50% of the time conditions are expected to be more severe, and 50% of the time conditions are expected to be less severe. Pasquill Class F was considered to be equivalent to 95% meteorology; that is 5% of the time it is more severe and 95% of the time it is less severe. Analyses performed by the National Oceanic and Atmospheric Administration (NOAA, 1976) confirm that this assumption is reasonable.

Upon comparing the resultant probabilities to the 1×10^{-7} per year criterion, the most severe atmospheric (Pasquill Class F) results were presented if warranted by the cut-off. If the probability was less than the 1×10^{-7} cutoff, the consequences resulting from release of 1% of the corrosion products (Pasquill Class D) would be presented at the minimum. This later case never occurred. This method of determining the atmospheric condition and corresponding release fraction is consistent with the U.S. Department of Energy's, Office of Environmental Management and Idaho National Engineering Laboratory, Environmental Waste Management Programs Environmental Impact Statement (DOE, 1995).

Careful attention was paid to ensure that the probabilities were not calculated for such small categories that the resulting probabilities were less than the criterion and results would inadvertently present less severe consequences.

6. ROUTING ANALYSIS

In order to assess the radiological risk associated with transportation, it was necessary to determine route characteristics based on the origin and destination of each shipment as well as the method of shipment.

For naval reactor compartment shipments, the origin is the shipyard location where the reactor compartment has been removed form the ship. In this analysis, the two possible points of origin are Puget Sound Naval Shipyard (PSNS) and Norfolk Naval Shipyard (NNSY). The destination is one of two burial sites, the Savannah River Site or the Hanford Site.

The method of shipment for each package type is shown in Table E-1. For the large packages (whole reactor compartments and reactor pressure vessels), the package is transported via barge over an ocean leg and a river leg, and then via transporter for land transport. The estimated mileage for each part of the shipment of the large packages is given in Table E-3

For the rail and truck shipment of the subdivided reactor compartment, INTERLINE and HIGHWAY were used to generate routing data.

7. INPUT PARAMETERS AND ASSUMPTIONS

The major input parameters and assumptions used to evaluate the radiological risks associated with the shipments identified in Table E-1 are provided in this section. A number of the input parameters were developed for these particular shipments while others are standard RADTRAN 4 computer code values. The standard RADTRAN 4 default values are provided in Table E-4. Exceptions to the default values are identified in Table E-4 and further discussed below. These are representative values for purposes of evaluation and may vary in actual practice.

Table E-3 Distance (km) for the Transportation of Large Packages

	OCEAN BARGE		RIVER BARGE	TRANSPORTER
PSNS to Hanford	Sound & Strait Ocean River TOTAL	241 261 166 668	Vancouver to Port of Benton 386	Port of Benton to Site 42
PSNS to Savannah River	Sound & Strait Ocean Panama Canal Savannah River TOTAL	241 12,260 82 0 12,583	Savannah to Barge Wharf 253	Barge Wharf to Site 16
NNS to Hanford	Elizabeth River Ocean Panama Canal Columbia River TOTAL	48 12,884 82 166 13,180	Vancouver to Port of Benton 386	Port of Benton to Site 42
NNS to Savannah River	Elizabeth River Ocean Savannah River TOTAL	48 885 0 933	Savannah to Barge Wharf 253	Barge Wharf to Site 16

7.1 Incident-Free Transportation

This section provides the input parameters and assumptions used to determine the radiological impacts associated with routine, incident-free (i.e., no accident) transportation of all of the package types under consideration.

7.1.1 Planned Shipments. Table E-5A provides a list of whole reactor compartment shipments (estimated size and estimated number of packages) that are possible from PSNS to the Hanford Site. Table E-5B provides a summary of shipments for the subdivided alternative from either of the two origins and to either of the two proposed destinations (estimated size and estimated number of packages).

Table E-4 Default Values for RADTRAN 4 Input Parameters

	RADTRAN 4 Input Parameter	Truck	Rail	Barge
1	Fraction of Travel in Rural Zone	0.90	0.90	0.90
2	Fraction of Travel in Suburban Zone	0.05	0.05	0.09
3	Fraction of Travel in Urban Zone	0.05	0.05	0.01
4	Velocity in Rural Zone (km/hr)	88.49	64.37	16.09*
5	Velocity in Suburban Zone (km/hr)	40.25	40.25	8.06*
6	Velocity in Urban Zone (km/hr)	24.16	24.16	3.2*
7	Number of Crew on Shipment	2.00	5.00	2.00*
8	Average Distance from Radiation Source to Crew During Shipment (meters)	3.10	152.40	45.70*
9	Number of handlings per shipment	0.0	2.00*	2.00*
10	Stop Time for Shipment (hr/km)	0.011	0.033	0.01*
11	Minimum stop time per trip (hr)	0.0	10.00	10.00*
12	Distance Independent Stop Time per Trip (hr)	0.0	60.0	0.0
13	Minimum number of Rail Inspections or Classifications	0.0	2.00	0.0
14	Number of Persons Exposed During Stop	50.0	100.0	50.0
15	Average Exposure Distance When Stopped (meters)	20.0	20.0	50.0
16	Storage Time per Shipment (hr)	0.0*	4.00*	24.00*
17	Number of Persons exposed During Storage	100.0*	100.0*	100.0*
18	Average Exposure Distance During Storage (Meters)	100.0*	100.00*	100.00*
19	Number of Persons per Vehicle Sharing the Transport Link	2.0	3.00	0.0
20	Fraction of Urban Travel During Rush Hour	0.08	0.0	0.0
21	Fraction of Urban Travel on City Streets	0.05	1.0	0.0
22	Fraction of Rural and Urban Travel on Freeways	0.85	0.0	0.0
23	One-Way Traffic Count in Rural Zones	470.00	1.00	0.0
24	One-Way Traffic Count in Suburban Zones	780.00	5.00	0.0
25	One-Way Traffic Count in Urban Zones	2,800	5.00	0.0

* Default values not used.

Table E-5A Package Data for Whole Reactor Compartments

Package Type	LA Class	OHIO Class	VIRGINIA Class	LONG BEACH Class
Whole Reactor Compartment via ocean barge, river barge, and transporter	42' long x 33' diam 62 pkgs	55' long x 42' diam 18 pkgs	37' high x 31' diam 16 pkgs	37' x 38' x 42' 2 pkgs

7.1.2 Package Size. The package sizes used in RADTRAN 4 are shown in Table E-6. The reasonability of the package sizes selected for this evaluation were confirmed using an independent computer code (SPAN4) having the explicit package dimensions modeled to calculate radiation levels. The SPAN4 calculated dose falloff was compared to that produced using RADTRAN 4 to confirm the reasonability on the package size input to RADTRAN 4.

7.1.3 Shipment External Dose Rate. The maximum gamma radiation level measured at one meter from the surface of the package is directly proportional to the incident-free predicted exposure. For the subdivided alternative, the shipment external dose rate was assumed to be 2.0 mrem/hr which is consistent with conservatisms achieved in design practice. For shipment of whole reactor compartments, the shipment external dose rate was assumed to be 2.8 mrem/hr based on historical data.

Table E-5B Packages Data for Subdivided Reactor Compartments

Package Type	LA Class	OHIO Class	VIRGINIA Class	LONG BEACH Class
Misc Components via Truck	8'x10'x40'	8'x10'x40'	8'x10'x40'	8'x10'x40'
Reactor Pressure Vessels via Barge	21' long x 11' diam	20' long x 15' diam	26' long x 12' diam	27' long x 15' diam
Steam Generators via Rail	14'x7'x19'	16'x8'x21'	NA	NA
Steam Generators via Truck	NA	NA	23' long x 5' diam	27' long x 6' diam
Pressurizers via Rail	23' long x 7' diam	28' long x 7' diam	25' long x 5' diam	28' long x 7' diam
Total Number of Packages	854	444	196	43

7.1.4 Transportation Distance and Population Densities. Section 7 provided a description of the general methodology used for determining transportation distances and the population densities along the transportation routes. In the analysis done for the U.S. Department of Energy's, Office of Environmental Management and Idaho National Engineering Laboratory, Environmental Waste Management Programs Environmental impact Statement (DOE, 1995), historical data were obtained on the distance traveled for shipments from the shipyards and prototype sites to the Expended Core Facility at the Idaho National Engineering laboratory. These data were averaged by origin and compared to the value calculated by INTERLINE. The actual data were approximately 11% higher than the distance predicted by INTERLINE on average. Therefore, consistent with the Environmental Waste Management Programs Environmental Impact Statement (DOE, 1995), INTERLINE distances in each populations density were increased by 11%.

Table E-6   Effective Diameter/Package Size for RADTRAN 4

Package Type	LA Class	OHIO Class	VIRGINIA Class	LONG BEACH Class
Whole Reactor Compartment	10.0 m	12.8 m	9.4 m	11.3 m
Miscellaneous Components	3.0 m	3.0 m	3.0 m	3.0 m
Reactor Pressure Vessel	3.4 m	4.6 m	3.7 m	4.6 m
Steam Generator	2.1 m	2.4 m	1.5 m	1.8 m
Pressurizer	2.1 m	2.1 m	1.5 m	2.1 m

Similarly, historical data for Navy shipments indicates that the distance traveled for highway shipment is typically 3% greater than that predicted by HIGHWAY. Therefore, the percentage of distance traveled in each population density calculated in HIGHWAY were increased by 3%.

7.1.5   Radiation Exposure Decreased Due to Distance. The RADTRAN 4 computer code calculates the gamma and neutron radiation exposure decrease based on distance from the package and package size. (Neutron calculations do not apply for defueled reactor compartment shipments because there is no neutron source.) For gamma radiation, the RADTRAN 4 computer code distance falloff calculations was consistent with the falloff predicted by SPAN 4 in free space.

7.1.6   Shipment Storage Time. Shipments of naval radioactive material would not be stored while in the process of being shipped; therefore there was no shipment storage time associated with any of the shipments.

7.2   Train Shipments

7.2.1   Train Velocity. The RADTRAN 4 computer code provides standard values for train speeds that are dependent on the population density. These default values were applied to the shipment of the smaller packages.

7.2.2   Train Stop Time. The RADTRAN 4 computer code provides standard values for train stop times that were used in this evaluation.

7.2.3   Number of Train Crew Members. The RADTRAN 4 computer code value for the number of train crew members is five. Although the items would be radioactive, they would not contain spent fuel and would not be considered to be a special shipment; therefore, the default value for the train crew is considered to be adequate. In the RADTRAN 4 computer code, exposure to the crew is not calculated.

7.2.4   Train Stop Shield Factors. For train stops, the standard RADTRAN 4 computer code gamma shield factor is 0.1. This value assumes the presence of substantial rail yard structures equivalent to approximately four inches of steel. Four inches of steel reduces gamma radiation exposure by more than a factor of ten. Therefore, a shield factor of 0.1 is considered to be reasonable.

7.2.5 Distance from the Source to the Crew. The RADTRAN 4 default of 152.4 meters was used for train shipments.

7.3 Truck and Transporter Shipments

7.3.1 Truck Velocity. For truck shipments, the RADTRAN 4 defaults were used in all three population density zones. For the transporter segment of large package shipment, the velocities are summarized in Table E-7.

7.3.2 Truck Transportation Crew. The RADTRAN 4 computer code default values for the truck crew were used for the truck shipments for the smaller packages. For the larger packages (whole reactor compartment or reactor vessel pressure vessel), the number of persons to be included in the transporter transportation crew is summarized in Table E-7.

7.3.3 Number of Truck Inspection Inspections. The shipments are inspected prior to leaving the shipyard. Otherwise, it is assumed that there are no inspections during transport.

7.3.4 Truck Stop Time. The RADTRAN 4 default values for the truck stop times were used for the evaluation of the smaller packages. For the shipment of the whole reactor compartments and reactor pressure vessels, the transporter stop time is summarized in Table E-7.

7.3.5 Distance from the Source to the Crew. The crew is assumed to be located 3.1 meters from the outside of the packages for the truck and the transporter.

7.4 Waterway Shipments

The standard RADTRAN values for waterway (i.e., barge) shipments were replaced by the values in Table E-7 as discussed below.

Table E-7   RADTRAN 4 Parameters for Waterway Shipments

Input Parameter	Ocean Barge	River Barge	Transporter
Velocity for rural areas	12.8 km/hr	13.1 km/hr	8 km/hr
Velocity for suburban areas	12.8 km/hr	13.1 km/hr	8 km/hr
Velocity for urban areas	12.8 km/hr	13.1 km/hr	8 km/hr
Stop and storage time	2.3 hours	29.0 hours	2.0 hours
Distance from the outside of the package to the crew	a) through the sound, the strait and the ocean, 221 meters b) through the mouth of the Columbia River, 51 meters	21 meters	3.1 meters*
Number of crew members	6	12	4

*RADTRAN 4 default

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7.4.1   Barge Transportation Crew. The barge transportation crew numbers (ocean and river) are summarized in Table E-7. These crew members are actually not for the barge but occupy the tugboat.

7.4.2   Barge Stop Time.   Barge stop times are summarized in Table E-7. The stop time for the river barge includes the time required to pass through the locks on the Columbia River for transport to the Hanford Site and the time to transfer the package from the barge to the transporter.

7.4.3   Barge Velocity.   The barge velocity for rural, suburban and urban population zones are summarized in Table E-7.

7.4.4   Barge Distance from the Shore.   RADTRAN 4 assumes a distance of 200 meters from the barge to the shore. For river transport, this is considered to be adequate. However, the ocean barge would be from 5 to 15 nautical miles offshore during the ocean leg of the transport of the large packages, resulting in off-link incident-free population exposure of zero for that link. An independent analysis that included an evaluation of population exposure at long distances confirms this conclusion. Therefore, for the portion of the route where the barge is in the ocean (versus the sound, the strait or the river) off-link exposure is considered to be zero.

7.4.5   Distance from the Source to the Crew.   For the transport of the barge with an ocean tugboat through the sound, the strait, and the ocean, the distance is 221 meters; for the transport of the barge with an ocean tugboat through the mouth of the river, 51 meters, and for the transport of the barge up the river using a river tugboat, 21 meters, This summarized in Table E-7. These distances were used in estimating exposure to crew members during shipment.

7.4.6   Shield Factor. A shield factor of 0.5 was applied to account for structural bulkheads between the crew and the package during transport.

7.5   Other Standard RADTRAN 4 Computer Code Values Used

The following standard RADTRAN 4 computer code values were reviewed and were determined to reflect the best estimate of current practices:

(1) Number of people per vehicle sharing the transport route (on-link).

(2) Traffic count passing a specific point - rural, suburban and urban zones.

(3) Average exposure distance when stopped.

(4) Persons exposed when stopped.

(5) Fraction of travel during rush hour, on city streets, and on freeways.

7.6   Exposure to Handlers

Handlers are defined to include all workers involved in the transfer of packages from one mode or location to another. Exposure to handlers is not included in this evaluation.

7.7   Accident Model for Transportation of Naval Reactor Compartments

This section provides the input parameters and assumptions used to determine the radiological impact for postulated accidents during transportation of the reactor compartments. The planned

shipments, transportation distances, population densities, and the percentages of travel in each population density described in Section 7.1 were used in the accident analysis. Unless otherwise described in this section, the standard values provided by the RADTRAN 4 and RISKIND computer codes were used.

7.7.1 Accident Probability. The probability of an accident by transportation mode was obtained from a report submitted to the U.S. Department of Energy's Reactor Technology and Transportation Division (Saricks, 1994). For the shipments from PSNS to Hanford, accident rates for the States of Washington were used. Otherwise, the U.S. averages were employed. The employed accident probabilities are presented in Table E-8 and are the same for rural, suburban, and urban areas except as noted.

The truck accident rates for shipments from PSNS to Hanford are best estimate rates based on the State of Washington Federal-Aided Interstate Urban and Rural accident rates (FAI-U and FAI-R) provided in the report (Saricks, 1994). Use of this state-specific FAI data is considered consistent with the HIGHWAY routing analysis which showed interstate to be the primary highway traveled from Bremerton to Hanford. For all other destination/origin combinations, the truck accident rates are based on the national average Federal-Aided Primary (FAP) highway accident rates provided in the report (Saricks, 1994). This simplified treatment of combining statewise accident rates and ensured a conservative model (FAP national rates are about 10% to 60% greater than corresponding FAI-R and FAI-U national rates).

Table E-8   Accident Probabilities

Transport Mode	National Average Probability (Accidents/km)	Washington State Probability (Accidents/km)
Truck	3.94×10^{-7}	2.50×10^{-7} (Rural) 1.61×10^{-7} (Urban) 1.61×10^{-7} (Suburban)
Rail	5.57×10^{-8}	3.49×10^{-8}
Pacific Ocean	1.7×10^{-6}	Same as national average
Atlantic Ocean	5.46×10^{-6}	NA
Inland Waterways	3.82×10^{-6}	· Same as national average

7.7.2 Severity Fractions. Accidents in which a shipment is subjected to various degrees of forces are assigned to an accident severity fraction category. In order to calculate the probability of a severe accident, the accident probability is multiplied by the severity fraction.

For purposes of determining the accident severity probability for reactor compartment shipments, a two category scheme was used. Category I applies to the probability of accidents which do not exceed the 10CFR71 limits and Category II applies to those which have a probability of severe accidents exceeding the limits with subsequent corrosion product release.

For the rail and truck shipments, the employed accident severity probabilities are same as those used for the "Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement" (DOE, 1995) for corrosion products release. That study conservatively identifies that for truck and rail accidents, a 99.4% probability exists for accident conditions that do not exceed the 10CFR71 criteria (i.e., category I). The remaining 0.7% and 0.6% are the Category II severe accident probabilities which result in release of corrosion products. DOE, 1995 also identifies a third category where there is a corrosion product release and fission product release. For these reactor compartments there is no fission product source or release and therefore a two-category release scheme for corrosion products is appropriate.

For the barge shipments a 99.65% probability of an accident not exceeding 10CFR71 was assumed for this evaluation. This is based on the values presented in Table 5-7 of the "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes" (NRC, 1977) for the sum of minor and moderate accident severity fractions. The source document (NRC, 1977) identifies 99.65% of all waterway accidents are minor or moderate type with release levels depending on container strength. However, evidence obtained after publication of the source document (NRC, 1977) and presented in a U.S. Department of Energy Environmental Assessment (DOE, 1994a) showed that no release can occur for Type B packages for these types of accidents. This 99.65% probability is also consistent with the U.S. Department of Energy's Environmental Assessment (DOE, 1994a) which employs 99.7% to be the Category I non-release probability for maritime shipments.

The overall resulting severity fractions that were use in the analyses are summarized in Table E-9.

Table E-9   Accident Severity Fractions

Category	Truck/Transporter Shipments	Rail Shipments	Barge Shipments
I	0.9940	0.9940	0.9965
II	0.0060	0.0060	0.0035

As stated above, the product of the accident probability and the severity fraction gives the severe accident probability. For barge shipments along the Pacific Coast and Atlantic Coast the severe accident probability per distance traveled is 5.95×10^{-9}/km (i.e., 1.704×10^{-6} accidents/km x 0.35×10^{-2} severity fraction) and 1.9×10^{-8}/km, respectively. These values are reasonably conservative when compared the severe accident in domestic waterborne barge probabilities presented in an Atomic Energy Commission survey of radioactive material transportation (AEC, 1972)(i.e., 1.9×10^{-9}/km).

7.7.3   Package Release Fractions.   The release fraction represents the fraction of the corrosion product inventory in the package that would be released into the atmosphere for a severe accident. The corrosion product release model accounts for all activated corrosion products which adhered to all wetted surfaces inside the reactor vessel and coolant system over plant life. Additionally, the corrosion products in the purification system components were assumed to be part of the reactor compartment shipment. Most of the corrosion product is strongly adherent and only a small

fraction would realistically be released if a severe accident were to occur. In developing a model of the activity released for a severe accident, it was conservatively assumed that 50% of the loose activity in the steam generators, and 10% of the loose activity in all other components (except purification filters and ion exchangers) are released from the package. The amount of loose activity is assumed to be 33% of the total corrosion product activity for all components based on an upper limit estimate from oxide film analysis of surveillance coupons from the S3G prototype reactor coolant system. The corrosion products released from the purification components were conservatively assumed to be 100% of the total available in the resin bed during shipment. This overall approach was derived from the model presented in "Final EIS on the Disposal of Defueled Naval Submarine Reactor Plants, Vol. 1, 1984" (USN, 1984). Application of this model results in about 32% to 40% release of the corrosion products from a whole reactor compartment for use in a severe accident scenario.

The severe accident release fractions employed in this evaluation by component are summarized in Table E-10. The corresponding whole reactor release fractions resulting from applying the Table E-10 values are 0.38. 0.32, 0.36 and 0.40 for the LOS ANGELES, VIRGINIA, OHIO, and LONG BEACH class ships, respectively.

7.7.4 Corrosion Product Activity. The corrosion product activities employed in the accident analyses were derived based on formulas that predict corrosion product deposition levels from reactor plant pipewall dose rate measurements with Cobalt-60 being the dominant radioisotope (Cobalt-60 contributes over 95% to the accident total exposure levels). The corrosion product activity estimates were calculated for the earliest time after reactor compartment shutdown for which disposal shipment could occur. The activities used in the risk analyses are projected end-of-life plant values based on the average over all ships of the same class with the first reactor core installed except for the USS LONG BEACH which is based on the last core. In the consequences analyses, the highest projected activity (peak) of all ships in the same class was used.

Table E-10   Corrosion Product Release Fractions

Category	Truck	Rail	Barge
I	0.0	0.0	0.0
Misc II	0.033	NA	0.033
Resin II	1.0	NA	1.0
Reactor Pressure Vessel II	0.033	NA	0.033
Steam Generator II	0.167	0.167	0.167
Pressurizer II	NA	0.033	0.033

7.7.5   Plume Release Height.   For the accident risk assessment, a ground level release was used in the RADTRAN 4 model. For the maximum consequence assessment, a plume release height of ten meters was used in the RISKIND model.

7.7.6   Direct Exposure from a Damaged Package. The radiation level following an accident was assumed to be at the 10CFR71 regulatory limit of one rem at one meter from the component surface.

7.7.7   Food Transfer Factors.   The food transfer factors for the RADTRAN 4 assessment were developed using the same method as the "Environmental impact Statement on Environmental Restoration and Waste Management Activities at the Idaho National Engineering Laboratory" (DOE, 1995). For shipments from PSNS to Hanford, the Washington State food transfer factors were used. For all other shipments, the food transfer factors were those that represented the U.S. average.

7.7.8   Distance from the Accident Scene to the Maximum Exposed Individual.   An assumption was made that the maximum exposed individual would be unshielded for the time that the plume passes by. The location of maximum exposure was also assumed to be at the location for which maximum exposure would occur (160 m to 400 m from the accident site). This location was determined using RISKIND based on the assumed atmospheric stability and plume release height.

7.7.9   RISKIND Population Density.   The standard national average for each population density from the RADTRAN 4 computer code was used for the RISKIND maximum consequence assessment. The assessment considers the population within 80 km (50 miles) of the site under both neutral and stable weather conditions. The population ranged from 1.5 million (urban) to 2,600 (rural).

8.   SUMMARY OF RESULTS

The results of the evaluation for shipment of 100 reactor compartments are summarized in Table E-11. Under incident-free conditions the whole reactor compartment shipment from PSNS is expected to have a lower risk of cancer fatalities than the subdivided alternative for any other origin/destination combination. Furthermore, the predicted health risk for incident-free shipments is greater than the predicted health risk due to an accident during shipment. This is because there is a low probability of a severe accident for the various transportation modes of interest. The health risk in the event that an accident does occur is evaluated as the maximum consequence to an individual and to the general public in rural, suburban, and urban population zones and is discussed separately.

The maximum consequences of an accident assuming a severe accident occurs have been evaluated for whole reactor compartment shipment and the subdivision alternative. The results are tabulated in Table E-12. Accident results are presented for both the maximally exposed individual and the general population. The transportation crew is considered to be part of the general population under accident conditions, so a member of the transportation crew could be the maximally exposed individual.

Table E-11   Shipment of 100 Reactor Compartments

	No. of Pkgs.	General Population (RADTRAN 4)				Transporatation Crew (RADTRAN 4)		MEI General Population (Formulas (1) and (2) Paragraph 4.2 scenarios)		MEI Occupational (Paragraph 4.2 scenarios)		Non-Radiological	
		Incident Free		Hypothetical Accident		Incident Free		Incident Free		Incident Free		Incident Free	Hypothetical Accident
		Exposure (Person-Rem)	Cancer Fatalities	Exposure (Person-Rem)	Cancer Fatalities	Exposure (Person-Rem)	Cancer Fatalities	Exposure (Person-Rem)	Cancer Fatalities	Exposure (Person-Rem)	Cancer Fatalities	Fatalities	Fatalities
Whole:													
PSNS to Hanf.	100	$5.81 \times 10^{+0}$	2.91×10^{-3}	8.38×10^{-1}	4.19×10^{-4}	$5.79 \times 10^{+0}$	2.32×10^{-3}	1.22×10^{-1}	6.11×10^{-5}	6.36×10^{-1}	2.54×10^{-4}	4.18×10^{-5}	9.47×10^{-4}
Subdivided:													
PSNS to Hanf.	1571	$1.10 \times 10^{+1}$	5.51×10^{-3}	3.98×10^{-2}	1.99×10^{-5}	$1.17 \times 10^{+1}$	4.66×10^{-3}	$1.28 \times 10^{+0}$	6.41×10^{-4}	5.11×10^{-0}	2.04×10^{-3}	3.10×10^{-3}	2.71×10^{-2}
PSNS to SRS	1571	$1.08 \times 10^{+2}$	5.42×10^{-2}	6.20×10^{-1}	3.10×10^{-4}	$9.35 \times 10^{+1}$	3.74×10^{-2}	$1.28 \times 10^{+0}$	6.38×10^{-4}	$4.72 \times 10^{+1}$	1.88×10^{-2}	2.56×10^{-2}	7.56×10^{-1}
NNS to Hanf.	1571	$1.19 \times 10^{+2}$	5.97×10^{-2}	7.52×10^{-1}	3.76×10^{-4}	$9.63 \times 10^{+1}$	3.86×10^{-2}	$1.28 \times 10^{+0}$	6.38×10^{-4}	$4.80 \times 10^{+1}$	1.92×10^{-2}	3.34×10^{-2}	7.81×10^{-1}
NNS to SRS	1571	$1.75 \times 10^{+1}$	8.72×10^{-3}	1.14×10^{-1}	5.72×10^{-5}	$1.78 \times 10^{+1}$	7.09×10^{-3}	$1.73 \times 10^{+0}$	8.61×10^{-4}	8.53×10^{-0}	3.41×10^{-3}	4.39×10^{-3}	1.18×10^{-1}
Comparison:													
Whole: PSNS to Hanf. versus Subdivided:													
PSNS to Hanf.	6.4%		52.8%		1280%		49.8%		9.5%		12.5%	1.3%	3.5%
PSNS to SRS	6.4%		5.4%		194%		6.2%		9.6%		1.4%	0.2%	0.1%
NNS to Hanf.	6.4%		4.9%		175%		6.0%		9.6%		1.3%	0.1%	0.1%
NNS to SRS	6.4%		33.4%		845%		32.7%		7.1%		7.4%	1.0%	0.8%

"PSNS" = "Puget Sound Naval Shipyard", "NNS" = "Norfolk Naval Shipyard, "Hanf." = "Hanford Site", "SRS" = "Savannah River Site"

Table E-12 Summary of Maximum Consequences Assuming an Accident Occurs

	Maximum Exposed Individual (Riskind)		Rural (Riskind)		Suburban (Riskind)		Urban (Riskind)	
	Exposure (rem)	Cancer Fatalities	Collective Dose (person-rem)	Cancer Fatalities	Collective Dose (person-rem)	Cancer Fatalities	Collective Dose (person-rem)	Cancer Fatalities
Whole Reactor Compartment	2.57	1.29×10^{-3}	4.41×10^2	2.20×10^{-1}	5.06×10^3	2.53	8.16×10^3	4.08
Subdivided Reactor Compartment	9.73×10^{-1}	4.86×10^{-4}	1.67×10^2	8.34×10^{-2}	1.91×10^3	9.57×10^{-1}	1.03×10^4	5.14

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